1090-WP-8-06
3 December 2001

<u>RTCA Special Committee 186, Working Group 3</u>

<u>ADS-B 1090 MOPS</u>

<u>Meeting #8</u>

Extended Squitter Interference Test Data Revised

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SUMMARY
At the 7th meeting, the FAA Technical Center (ACT-350) presented data from conducting the Enhanced Surveillance Processing Test Procedures as defined in 2.4.4.4 (1090-WP-6-04) utilizing the RF Measurement Facility and the associated enhanced reception implementations. The data was questioned as to the lack of symmetry in the performance curve associated with data points where the fruit is of higher amplitude relative to the signal. Action item 7-8 was assigned to address this problem. This paper addresses this action item and provides revised bench test data.

Introduction

At the 7th 1090-WG-3 meeting data was presented that showed the reception performance achieved by the three enhanced reception techniques developed at the FAA Technical Center when performing the draft test procedures defined in 2.4.4.4. Lincoln Labs also presented results from performing similar tests in simulation. When comparing the data from the two sources there were some profound differences. Figure 1 shows a comparison of the results from the Data Block Tests with 5 ATCRBS Fruit.

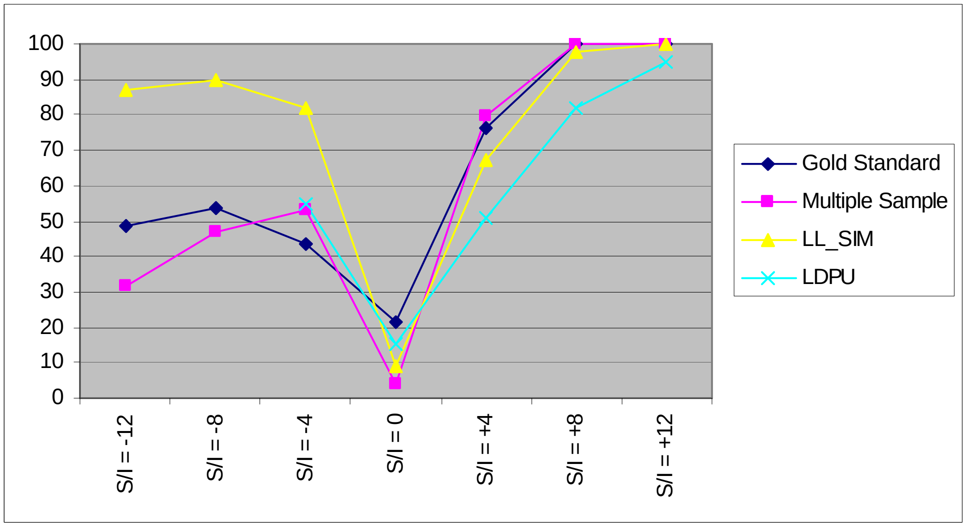

Figure 1 - Enhanced Surveillance Performance Comparison

As shown in figure 1, the Gold Standard and Multiple Sampling techniques performed as well or better than the simulation when the signal was equal to or greater in amplitude than the fruit. However when the fruit amplitude exceeds that of the signal the performance with the Gold Standard and Multiple Sampling techniques there was a dramatic decrease in performance as compared to the simulation. An estimated LDPU performance curve that was derived from the Johns Hopkins 1090 Lab test Results is included in the graph.

The enhanced decoding techniques are designed to perform reasonably well when interference is either significantly weaker or significantly stronger than the desired signal. The ideal performance curve should be somewhat symmetrical like the Lincoln Labs simulation curve. Perfect symmetry is not achieved because stronger fruit is more destructive than weaker fruit and stronger fruit can initiate re-triggering of the preamble detector resulting in the loss of a message in progress.

At the 7th meeting of 1090 working group 3, an action item was assigned to investigate why there is a lack of symmetry with the Gold Standard and Multiple Sampling technique curves. The investigation lead to the discovery of problems with both techniques and to the development of an improved Multiple Sample decoding technique that performs exceptionally well and is achieved with a simpler algorithm for determining bit and confidence data. This paper contains the new performance curves with the improved Multiple Sample technique and Gold Standard, and a description of the new technique.

The Gold Standard and Multiple Sample Technique Performance Problems

Analysis determined that the similar poor performance of both techniques on the left side of the curve was due to two different reasons. The Gold Standard technique too often declares high confidence with the bit value wrong, resulting in a bad message that cannot be corrected because high confidence bits can not be changed. The Multiple Sample technique declares low confidence too often that results in bad messages that cannot be corrected due to widely scattered and over abundant low confidence bits. (The conservative correction technique can not be activated if the low confidence bits span more than 24-bits, and the Brute force technique can not be applied of there are more than 5 low confidence bits total)

The problem with the Gold Standard technique was in the pattern look-up tables. It was not determined what caused the problems with the look-up tables generated at the Technical Center. As a resolution, Lincoln Laboratories generated new 5-5 tables that were loaded into the RMF Gold Standard software. The resulting performance with the new tables is significantly improved.

To correct the problem with the Multiple Sampling technique, a new bit and confidence declaration algorithm was developed that not only performs better, but is also a simpler process. The performance data with the new techniques is provided below.

Data Block Tests with ATCRBS Fruit (2.4.4.4.3.1)

Tests were conducted to inject extended squitter messages with ATCRBS fruit according to 1090-WP-6-04 2.4.4.4.3.1. Table 1 shows the average reception probability for the 2 improved enhanced reception methods with 1 through 5 ATCRBS fruit. Each value is the average of all 7 relative amplitudes.

Number of Fruit	1	2	3	4	5
Improved Multiple Sample	99.91	96.81	90.5	83.9	78.06
Improved 5-5 Tables	99.36	96.04	88.84	83.06	75.91

Table 1- Data Block Tests with ATCRBS Fruit - Average Reception Probability

The data in Table 1 corresponds to table 2.4.4.4.3.1 in the proposed Enhanced Surveillance Processing Test Procedures. Figure 2 shows a graphical representation of the same data. There were no occurrences of undetected errors during these tests.

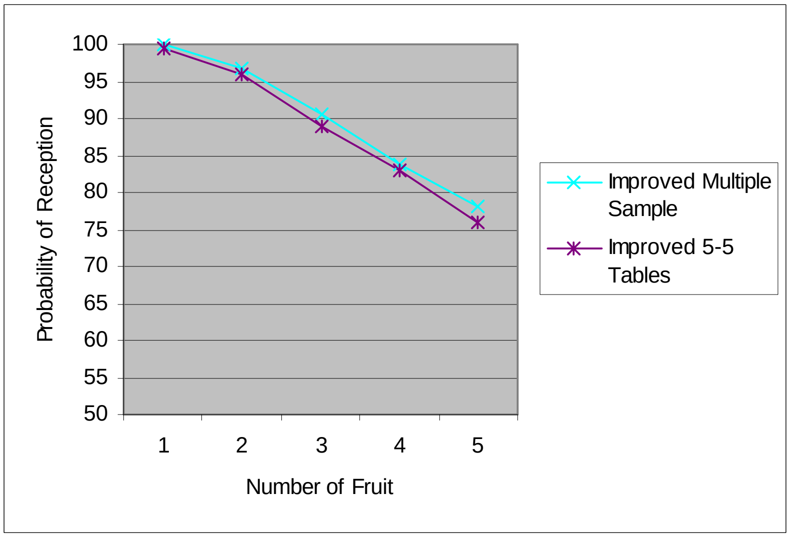

Figure 2 - Average Reception Performance with the Improved Enhanced Reception Techniques – Data Block Tests with ATCRBS Fruit

Data Block Tests with Mode S Fruit (2.4.4.4.3.2)

Tests were conducted to inject extended squitter messages with Mode S fruit according to 1090-WP-6-04 2.4.4.4.3.2. The tests were conducted with the two improved techniques. Table 2 shows the reception probability for the enhanced reception methods for each of the 4 relative amplitudes.

Relative power, (S/I) dB	0	+4	+8	+12	Average
Improved Multiple Sample	0.7	50.7	100	100	62.85
Improved 5-5 Tables	1.3	49	100	100	62.575

Table 2 - Data Block Tests with Mode S Fruit

The data in table 2 corresponds with table 2.4.4.4.3.2 in 1090-WP-6-04. There were no occurrences of undetected errors recorded during the tests with Mode S fruit. The tests were repeated between relative amplitudes of 0 and +8 dB to get a more viewable probability curve. The data is presented in Table 3 and Figure 3.

Relative power, (S/I) dB	0	+1	+2	+3	+4	+5	+6	+7	+8
Improved Multiple Sample	0.4	0.9	1.7	2.6	50.7	68.2	95.4	100	100
Improved 5-5 Tables	1.2	1	2.5	3.2	51.8	65	94.8	100	100

Table 3 - Data Block Tests with Mode S Fruit – 1 dB Steps

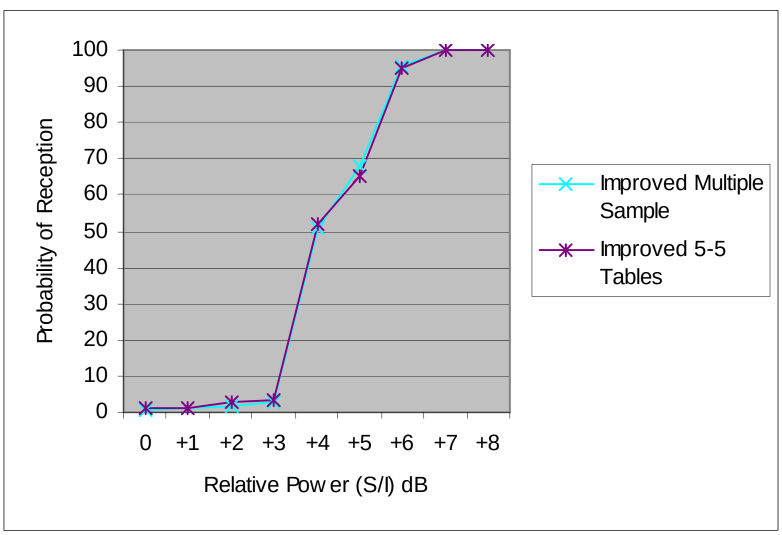

Figure 3 - Data Block Test with Mode S Fruit – Reception Probability Curves

Combined Preamble and Data Block Tests with ATCRBS Fruit (2.4.4.4.6)

The combined preamble and data block tests with ATCRBS fruit were conducted according to 1090-WP-6-04 2.4.4.4.6. The tests were conducted with the 2 improved enhanced reception techniques. Table 4 shows the average reception probability for the enhanced reception methods with 1 through 5 ATCRBS fruit. Each value is the average of all 7 relative amplitudes.

Number of Fruit	1	2	3	4	5
Improved Multiple Sample	99.79	97.51	93.54	88	82.19
Improved 5-5 Tables	99.39	96.73	92.79	87.46	81.7

Table 4 - Combined Preamble and Data Block Tests with ATCRBS Fruit - Average Reception Probability

The data in Table 4 corresponds to table 2.4.4.4.6.1 in the proposed Enhanced Surveillance Processing Test Procedures. Figure 4 shows a graphical representation of the same data. There were no occurrences of undetected errors during these tests.

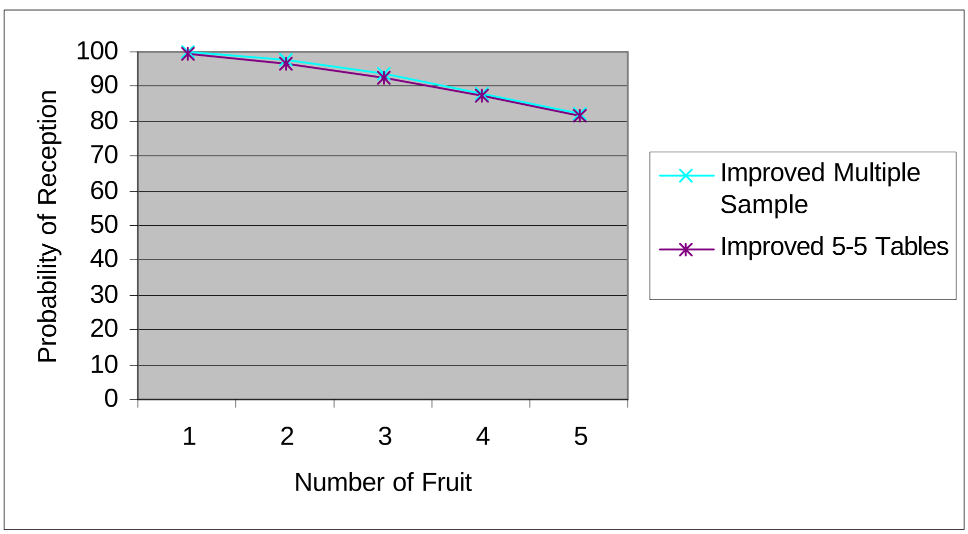

Figure 4 - Average Reception Performance of the Enhanced Reception Techniques – Combined Preamble and Data Block Tests with ATCRBS Fruit

Detailed Data

The following series of graphs show the performance curves for the two improved enhanced reception techniques for each number of ATCRBS fruit at each relative amplitude.

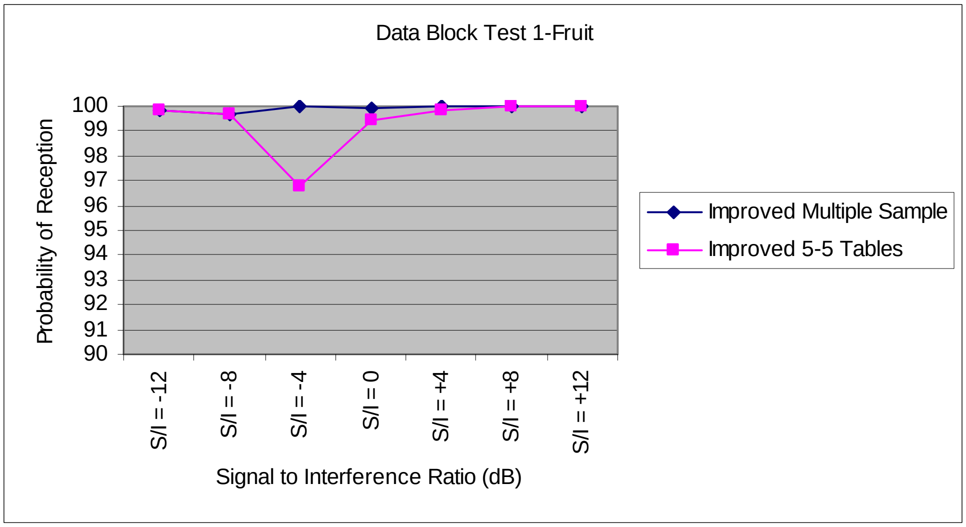

Figure 5 – Data Block Tests with 1 ATCRBS Fruit

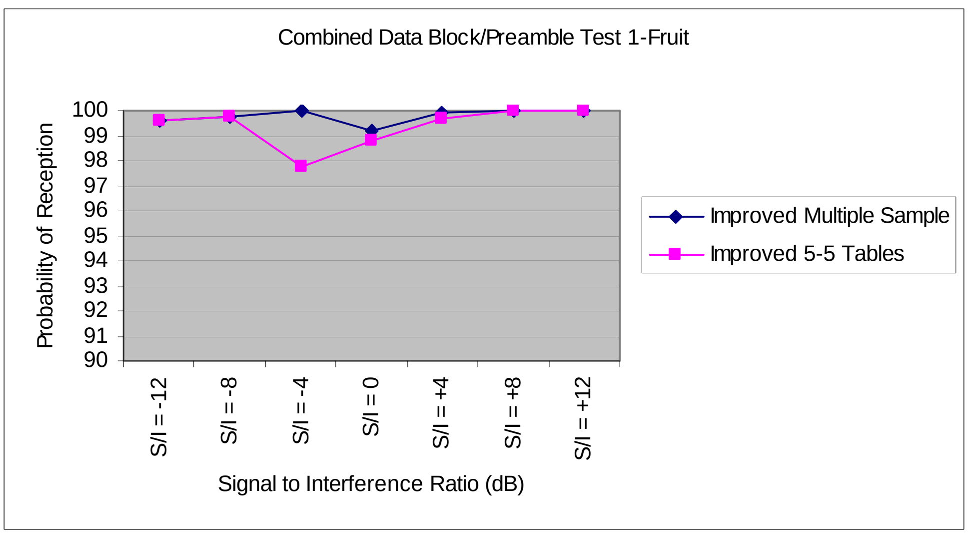

Figure 5A – Combined Data Block/Preamble Test with 1 ATCRBS Fruit

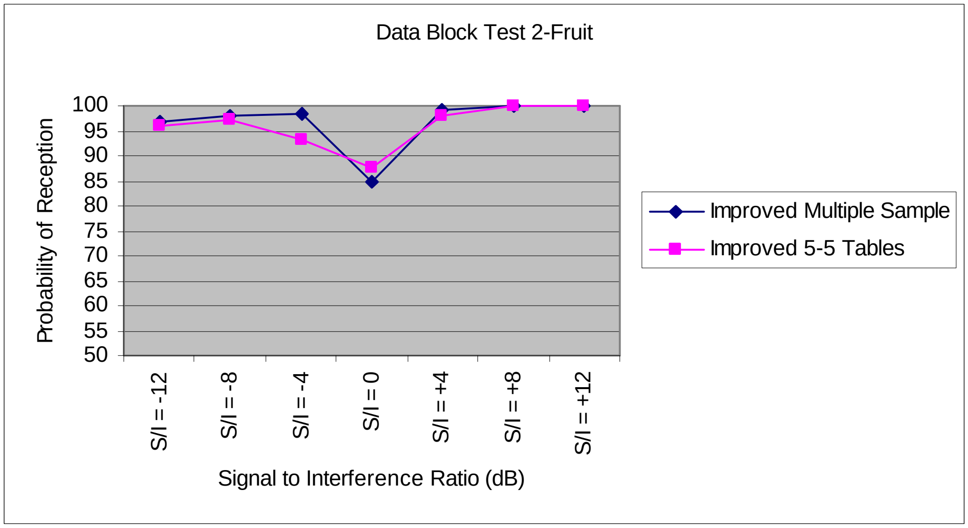

Figure 6 – Data Block Tests with 2 ATCRBS Fruit

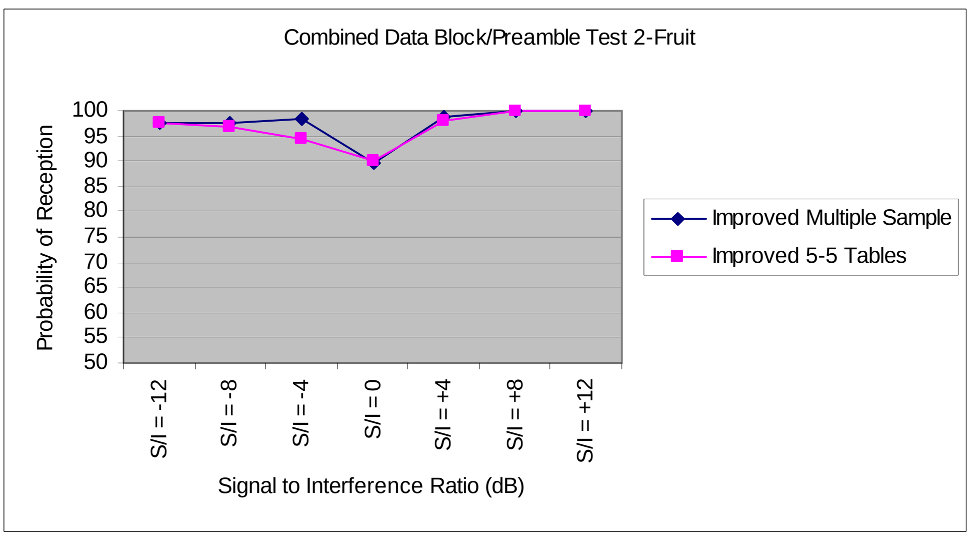

Figure 6A – Combined Data Block/Preamble Test with 2 ATCRBS Fruit

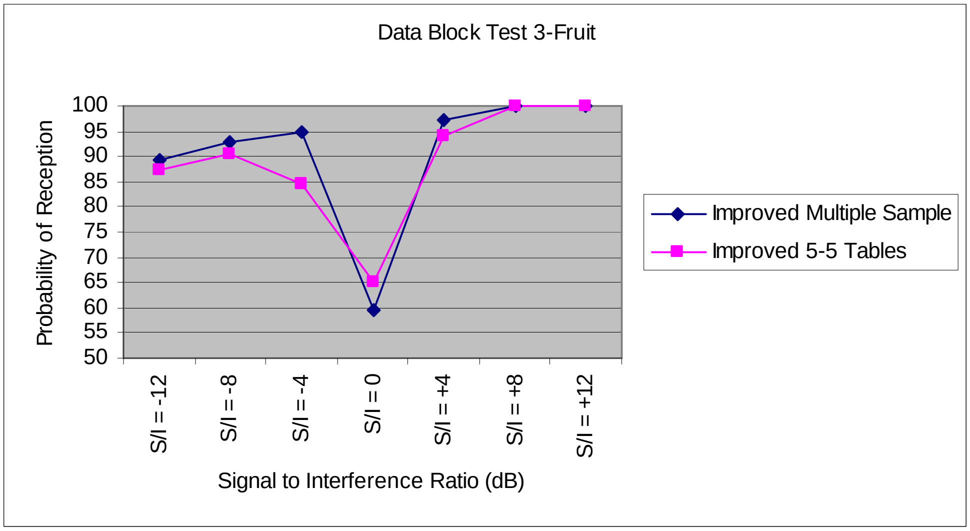

Figure 7 – Data Block Tests with 3 ATCRBS Fruit

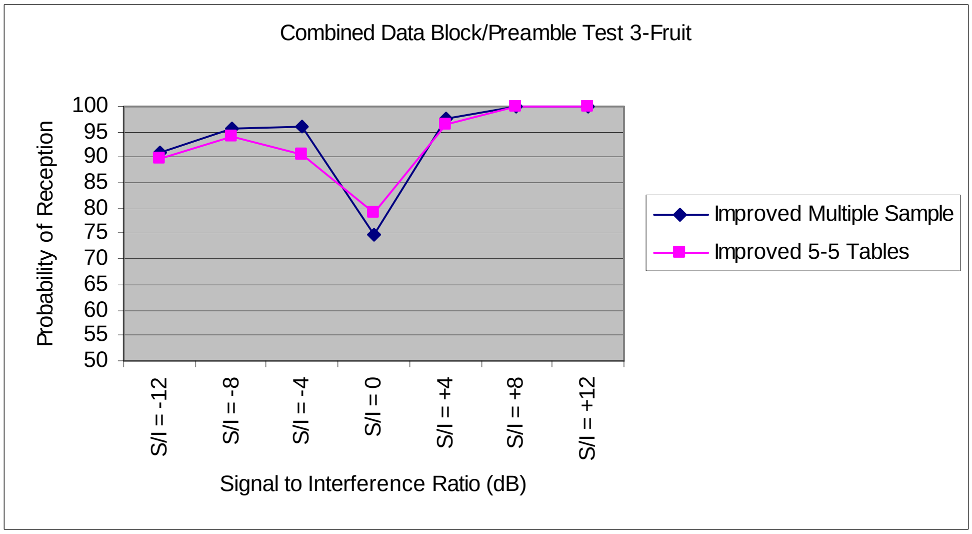

Figure 7A – Combined Data Block/Preamble Test with 3 ATCRBS Fruit

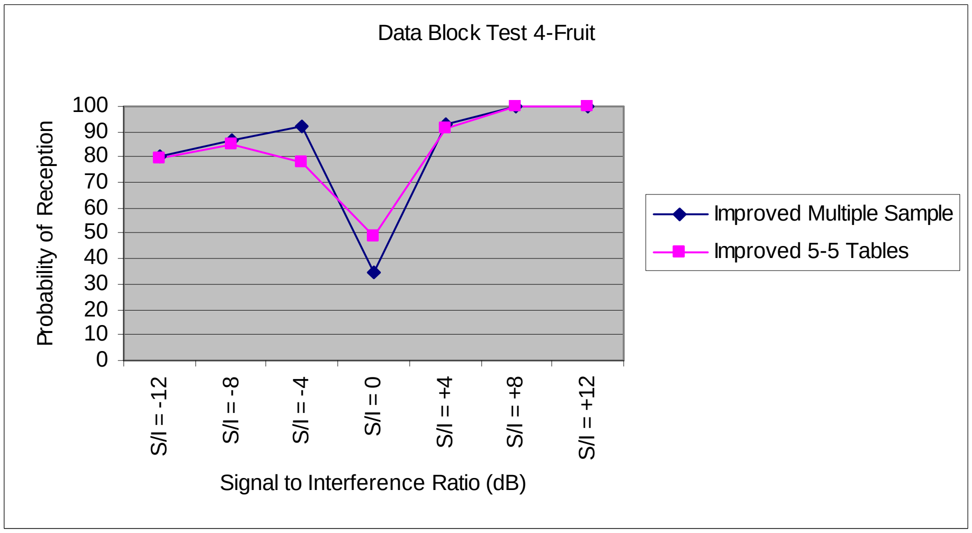

Figure 8 – Data Block Tests with 4 ATCRBS Fruit

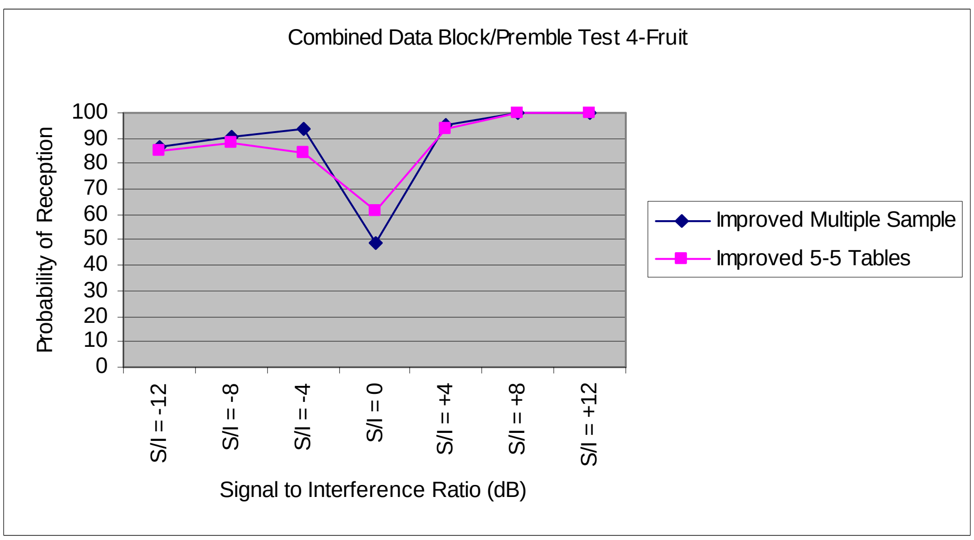

Figure 8A – Combined Data Block/Preamble Test with 4 ATCRBS Fruit

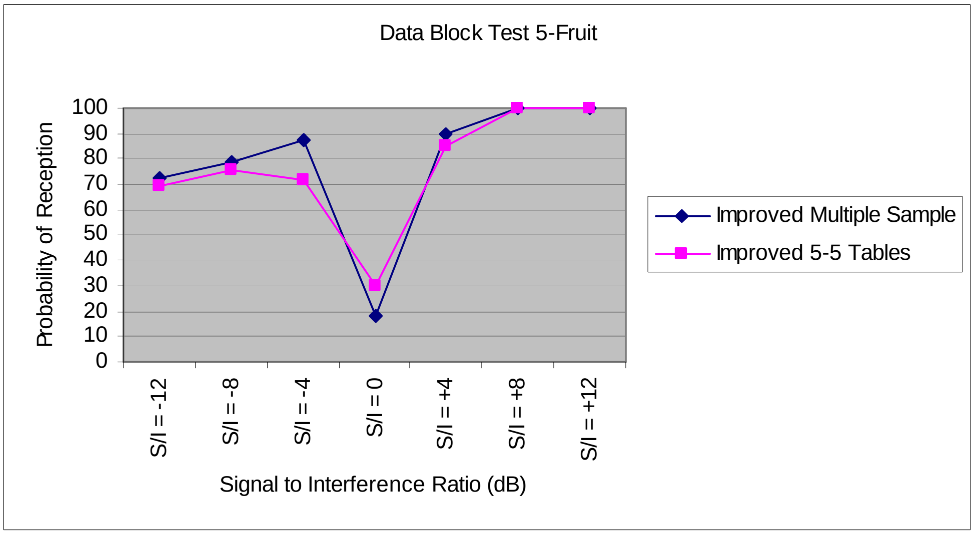

Figure 9 – Data Block Tests with 5 ATCRBS Fruit

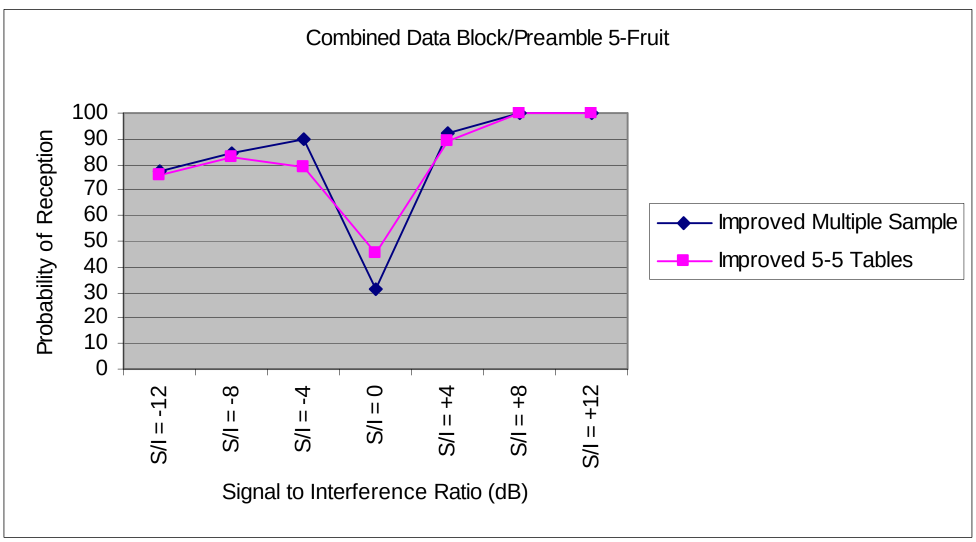

Figure 9A – Combined Data Block/Preamble Test with 5 ATCRBS Fruit

Symmetry

The performance curves with the improved enhanced techniques do not appear to have the near symmetry that is theoretically expected of a properly working enhanced decoder. The performance is significantly lower when the fruit is higher in amplitude than when the fruit is lower in amplitude relative to the signal.

There are two reasons that messages are lost when the fruit is more than 3 dB stronger than the signal. One is that stronger fruit, especially three or more fruit can be too destructive to a signal to properly decode or even correct the message. The other is that the fruit can combine with the data block pulses of the signal and cause the decoder to re-trigger. Analysis reveals that a large number of the messages lost at the three data points where the fruit is stronger than the signal are due to re-triggering the decoder. The RMF software allows the messages that are lost due to re-triggering to be decoded by the bit and confidence decoder and error correction process as well as other messages and optionally be included in the output. Figure 10 shows the performance curve with the improved Multiple Sample technique for 5 ATCRBS fruit and a partial curve for the three data points with the successfully decoded messages with re-trigger victims included.

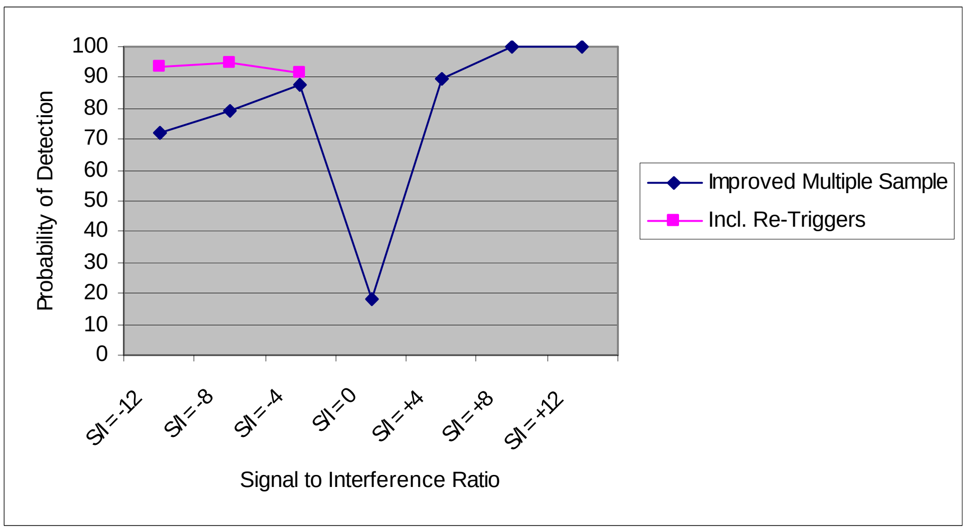

Figure 10 – Improved Multiple Sample Symmetry with Re-trigger Victims Included (5 fruit)

Figure 10 shows that the Improved Multiple Sample bit and confidence decoder in combination with error correction is able to properly decode 90% or more of signals at 6 of the test points. The hybrid performance curve shows that the improved Multiple Sample bit and confidence decoding scheme is capable of producing the expected near symmetrical curve and that the asymmetry is largely due to the re-triggering of the decoder. A symmetrical curve is not achieved when re-triggering is enabled. Similar results are achieved with the 5-5 table method.

NOTE: It has been determined that the Lincoln Labs simulation used to produce the curve in Figure 1 did not include a re-triggerable preamble detector and therefore produces a performance curve that is more symmetrical than can be achieved when re-triggering is enabled.

Improved Multiple Sample Bit and Confidence Decoder algorithm

The improved multiple sample technique is an alternative enhanced reception technique that does not use look-up tables to determine bit and confidence values. Instead, the amplitude of the ten samples per bit are used to determine if the bit is a one or a zero by comparing each sample to the signal reference level. Using all ten samples, 2 scores are determined. The one score is based on how well the sample pattern resembles a 1-bit, and the zero score is determined by how well the sample pattern resembles a 0-bit. The bit value is determined by which score is higher and high confidence will be assigned if the difference is higher than a threshold value.

The algorithm proceeds as follows:

The multiple sample method uses the amplitude of each sample and counts the number of samples in each chip that:

A. Is within the + or – 3 dB band centered at the preamble reference level
B. Is more than 6 dB below the preamble reference level

Four counts are determined:

ONEChipA = # of samples in the 1 chip half of type A (0-5)
ONEChipB = # of samples in the 1 chip half of type B (0-5)
ZEROChipA = # of samples in the 0 chip half of type A (0-5)
ZEROChipB = # of samples in the 0 chip half of type B (0-5)

The scores are determined:

ONEScore = ONEChipA – ZEROChipA + ZEROChipB – ONEChipB
ZEROScore = ZEROChipA – ONEChipA + ONEChipB – ZEROChipB

Whichever score is greater determines the bit value. If there is a tie it defaults to 0. If the difference in scores is 2 or more it is high confidence.

A variation of this method that yields slightly better results is to give more weight to the middle three samples of each chip by doubling their counts (each count then has a range of 0-8). With this variation, high confidence is awarded if the difference is 3 or more. Weighting is appropriate because it gives more attention to samples that are away from the transition areas of the pulses. The improved multiple sample method used for the data presented in this report uses this variation.